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We wished to determine if descent or oxygen is more effective for treatment of high altitude pulmonary edema (HAPE). We compared a lightweight (4 kg) hyperbaric chamber (a simulated descent of 1700m) at 4300 meters on Mt. McKinley (440 torr). Ten control subjects and nine HAPE subjects were given one hour of oxygen breathing (~28% O_2) and one hour of pressurization at 110 torr (2.1 psi) in the bag in a randomized order. Alveolar oxygen pressures were matched for the two treatments to determine if pressurization had benefits in addition to raising the inspired oxygen pressure. SaO_2% increased with both treatments (32% increase with pressurization vs 31% with oxygen). Symptomatic improvement was similar. A drop in hemoglobin was observed with pressurization (11% decrease in HAPE vs 3% in controls), suggesting a rapid flux of fluid into the intravascular compartment as previously reported. The portable hyperbaric chamber appears to be an effective, safe and practical method of treating mountain sickness and pulmonary edema, avoids the weight and expense of oxygen cylinders, and

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19. Abstract (continued)

can be used for long periods of time. Increasing the PO_2 by pressurization or by raising inspired PO_2 may be equally effective in improving oxygenation. Pressurization may be more effective in mobilizing extravascular fluid. Further research is needed to determine the optimal length of treatment with the hyperbaric chamber, the reoccurrence of illness after hyperbaric treatment, and whether oxygen or pressurization is more effective for treatment of high altitude illness.

FOREWORD

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Peter H. Hackett, MD 31 Dec 88

PI Signature Date

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INTRODUCTION

Although, hypoxia is assumed to be the cause of altitude illness, clinicians have commonly observed descent to be superior to oxygen for treatment of both acute mountain sickness (AMS) and high altitude pulmonary edema (HAPE) (1). Descent, rather than oxygen, is actually considered the treatment of choice for all forms of altitude illness. Since oxygen breathing generally provides a partial pressure of oxygen greater than that obtained with the usual descent of 1000 meters or so, speculation has developed for a role of barometric pressure changes *per se* in treatment of altitude illness (2),and correspondingly a role in the pathophysiology of altitude illness. The two treatments have never been compared scientifically. Preliminary work at Pheriche, Nepal (4243m), with a hyperbaric chamber which simulated descent of 2750 meters (3.3 psi), verified the usefulness of pressurization for treatment of altitude illness, but the investigators made no comparison with oxygen therapy (3). Surprisingly, the literature is lacking not only reports on the comparative effects of hyperbaria and oxygen therapy at altitude, but also the physiology of reversal of altitude illness with descent or oxygen (4). Understanding the physiology of recovery would greatly aid understanding the pathophysiology of high altitude illness, leading to improved prevention and treatment. We compared hyperbaria (simulated descent) with oxygen breathing for treatment of the most important and lethal form of altitude illness, high altitude pulmonary edema (HAPE) to determine: 1) if descent is truly superior to oxygen therapy; and 2) a possible mechanism by which pressurization and oxygen improve HAPE. These issues are especially relevant to the military situation in which troops may have to be deployed to high altitude areas.

Preliminary Studies

Dr. Hackett, with Hamish MacInnes of Scotland, designed, built and tested one of the first hyperbaric chambers for treatment of high altitude illness. It was installed at Pheriche, Nepal (4243 meters) in 1976. Although empirically found effective to

treat AMS and HAPE, the lack of instrumentation precluded any comparison of pressurization with oxygen therapy, or a physiological approach to mechanisms. Subsequently, Japanese investigators, in association with Dr. Hackett, used a new chamber at Pheriche, and showed in 15 subjects with various degrees of AMS (one with combined HAPE and cerebral edema), a remarkable decrease in symptoms within thirty minutes, associated with a significant decrease in heart and respiratory rates, and an increase in arterial oxygen saturation (5). They used a pressure of 170 torr (3.3 psi), equivalent to a drop in altitude of approximately 2,750 meters. Thirty normal controls at altitude were also pressurized for 30 minutes. In these control subjects they found significant changes in hematologic indices (Appendix). The authors assumed that the sick persons underwent the same hematologic changes, but made no such measurements in the ill group. They suggested that the mechanism of benefit was an increase in alveolar and arterial oxygen, and changes in blood rheology (speculation). However, another interpretation of their data is that a rapid redistribution of fluid into the vascular compartment took place, as shown by the drop in hemoglobin and red cell count (in the controls). If this same fluid shift occurred in the ill group, some improvement in symptoms could be attributed to a decrease in brain and lung hydration. Based on these preliminary studies, we examined the change in hemoglobin in both well controls and those with HAPE, in addition to our primary goal of a comparison of hyperbaria and oxygen.

BODY

Experimental Design and Methods

Subjects were 4 climbers ill with high altitude pulmonary edema, and 10 well control subjects. Baseline measurements included heart rate, respiratory rate, end-tidal oxygen and carbon dioxide, arterial blood gases (HAPE group only), arterial oxygen saturation by pulse oximeter, and hemoglobin concentration. Subjects were crossed-over so they received both treatments on the same day in random order. The

oxygen treatment consisted of breathing for one hour, gas with an F_IO_2 between 25% and 28% (mean 26%), adjusted to match calculated alveolar O_2 in the pressure chamber. This supplemental oxygen was administered with the subject supine, to control for body position. The hyperbaric treatment consisted of pressurization for one hour to a total pressure of 557-561 torr (110 torr, or 2.13 psi over ambient, which varied from 447 to 450 torr).

Hyperbaric Chamber

The chamber was made of a lightweight coated nylon material (Hyperbaric Mountain Technologies; Boulder, Colorado). The chamber had a full-length zipper, a plastic window for viewing the subject, pass-throughs for monitoring wires and gas sampling, and a pressure release valve to vent air to the outside. An electric air compressor pressurized the chamber. Gas composition of the chamber was continuously monitored by O_2 and CO_2 analyzers. Flow-through ventilation in the bag was inadequate to prevent some CO_2 accumulation, which averaged 1.8% (F_ICO_2 = 0.018). No patients developed complications while in the pressure bag.

Protocol

Subjects were climbers coming through the research camp at 4300 meters. Those ill with high altitude pulmonary edema and climbers without any symptoms were recruited to participate in the study.

High altitude pulmonary edema was diagnosed by the presence of all of the following criteria: significant arterial desaturation (SaO_2% at or below 70%, which is 3 standard deviations below the acclimatized mean at 4300 meters on Mt. McKinley), rales, and dyspnea on exertion. Minor criteria (usually present, but absence did not exclude the diagnosis) included cough, dyspnea at rest, tachycardia and tachypnea. Four well controls were solicited from the research camp staff, and six from climbers acclimatizing well. Climber controls and camp staff had similar altitude exposure prior to being studied, which was more time at altitude than the HAPE subjects (13 days for

control group versus 5 days for the HAPE group above 2100m, 8 days versus 1 day at 4300m).

Medical history was recorded and informed consent obtained. Supine vital signs were recorded, and then resting $P_{ET}O_2$, $P_{ET}CO_2$ and SaO_2 were measured. In the HAPE group, arterial blood gases sampled from radial artery blood were measured with an IL Micro 13 analyzer. Hemoglobin was measured on the arterial blood in the HAPE group using the HemoCue fast response instrument, and on fingerstick specimens in the control group.

With monitoring in place, the subject then began either one hour of supplemental oxygen breathing or one hour of pressurization in the bag. Heart rate, respiratory rate, SaO_2%, $P_{ET}O_2$ and $P_{ET}CO_2$, chamber PO_2, PCO_2 and barometric pressure were monitored continuously; we recorded measurements every five minutes. At the end of one hour all measurements were repeated and the first treatment trial terminated. After approximately another hour, subjects received the second treatment for one hour, with the same measurements.

Data Collection and Analysis

The pre-test and post-test values for physiological changes from baseline for each treatment were statistically evaluated by analysis of variance for repeated measures, with Tukey's test for post-hoc analysis.

RESULTS

Subjects

Because of equipment failure, we were not able to study as many HAPE subjects as planned. Two hyperbaric chambers failed and could not be repaired on-site. Another unit had to be airlifted to the camp, causing a delay. We completed the protocol on four subjects who met our strict criteria for HAPE and ten control subjects.

Baseline Measurements

At baseline, before any intervention, the HAPE group had lower SaO_2% and higher heart rates compared to controls. Arterial blood gases, done only in the HAPE group, revealed severe hypoxemia with hypocapnic alkalosis (see Appendix).

Treatment Trials in the HAPE Group

We attempted to match end-tidal oxygen pressures for the two treatments, in order to uncover any possible benefit of pressurization in addition to benefits obtained from raising inspired oxygen pressure. Because of the small amount of CO_2 which accumulated during the chamber run (mean 1.8%), inspired O_2 was slightly lower in the chamber (mean P_IO_2 = 101±0.8 torr in the chamber versus 105±2.3 torr with O_2 breathing), and end-tidal CO_2 was higher (Table). End-tidal O_2 values, however, were quite similar for the two treatments. Arterial oxygen saturation (SaO_2%) increased with both treatments (42% increase with pressurization versus 44% increase with oxygen breathing, Table). Heart rate decreased similarly with the two treatments.

A decrease in hemoglobin concentration was observed in 2 of the 3 subjects in the HAPE group with reliable measurements (-5.2% and -11.3%, no change in the third subject) suggesting a rapid flux of fluid into the intravascular compartment.

Clinical improvement in the HAPE group was similar with the two treatments: all subjects reported improvement of chest congestion and shortness of breath. There were no untoward effects with either treatment.

Treatment Trials in the Control Group

The control group subjects showed an increase in SaO_2% with pressurization and oxygen, a decrease in heart rate, and no significant change in hemoglobin (Table). Compared to the HAPE group, the SaO_2 and heart rate changes were in the same direction, but less marked. Only the HAPE group displayed the change in hemoglobin with pressurization.

CONTROLS

	BAG			OXYGEN		
	Pre	Post	%Change	Pre	Post	%Change
SaO_2 (%)	86.2±0.7	94.8±0.4	9.1±0.8	88.4±0.9	95.6±0.5	7.5±0.9
$P_{ET}O_2$	55.1±1.7	79.2±2.2	30±3.0	57.8±2.6	76.3±2.9	23.6±3.5
$P_{ET}CO_2$	24.6±1.0	24.1±1.5	-5.2±8.4	24.4±1.5	26.1±0.8	5.3±5.2
Heart Rate	74.7±3.6	68.3±4.0	-10.4±3.5	71.5±4.6	64.4±3.4	-11.6±5.1
Hemoglobin (%)	16.8±0.5	16.3±0.5	-3.2±2.4	16.4±0.5	17.2±0.5	2.0±2.4

HAPE

	BAG			OXYGEN		
	Pre	Post	%Change	Pre	Post	%Change
SaO_2 (%)	59.8±4.6	84.1±3.9	42.4±4.2	60.0±4.5	79.8±9.0	43.8±6.0
$P_{ET}O_2$	51.8±2.8	71.6±2.4	39.2±6.6	49.7±2.9	70.4±1.8	51.3±3.3
$P_{ET}CO_2$	23.2±2.2	30.2±3.4	29.4±2.9	24.3±2.8	24.4±2.6	2.5±7.9
Heart Rate	87.5±1.3	76.0±2.2	-13.2±1.2	89.8±2.6	77.0±2.7	-17.4±1.1
Respiratory Rate	23.5±2.1	18.3±1.0	-28.7±3.1	25.3±1.7	N/A	
Hemoglobin (%)	15.3±0.9	14.4±0.4	-5.7±3.1	14.7±0.5	N/A	N/A

DISCUSSION

The main finding of this study is that in subjects with high altitude pulmonary edema, pressurization to 2 psi in a hyperbaric chamber provided equal benefit to breathing supplemental oxygen providing an equivalent alveolar oxygen pressure. This suggests that, at least for the first hour of treatment, descent is not superior to oxygen. Secondly, the treatment of pulmonary edema with pressurization appeared to result in a flux of fluid into the intravascular compartment. Thirdly, the portable fabric hyperbaric chamber appears an effective, safe, and easy to use means for both treating pulmonary edema, and for studying the physiology of the illness.

This study has some limitations. One was having to use 2 psi in the chamber, instead of 4 psi which we had hoped to use. Therefore, physiologic changes were not as marked as we expected. We exploded two of the prototype devices when pressurizing to 4 psi, and after that used a maximum pressure of 2 psi; there were no more device failures. Another limitation is that each treatment was used for only one hour. Use in the field will, of course, mandate chamber runs of considerably longer length and differences between descent and oxygen may become apparent only with longer trials. A minor limitation of the study was a accumulation of 1-2% CO_2 in the chamber, which made it necessary to "fine tune" the F_IO_2 to match the alveolar PO_2 of the chamber. The fact that we studied only HAPE patients may be viewed as a limitation. Although we had hoped to study patients with acute mountain sickness, the patients with HAPE were a higher priority and time was insufficient to also study AMS HAPE, however, is a life-threatening illness for which the pressure bag will be most useful.

The finding that both methods of increased oxygen delivery, either by pressurization or increased F_IO_2, appeared to be equally effective was somewhat surprising. We had postulated pressurization as more effective, based on decades of uncontrolled clinical observation. However, these empirical observations have many

limitations. For example, oxygen has often been declared ineffective when used in insufficient quantity or for insufficient duration. This pilot study may even point to oxygen being superior to descent. Since we were limited to 25-28% inspired oxygen, in order to match alveolar gas tension with pressurization limited to 2 psi, it may be that treatment with a higher F_IO_2 would actually be more effective than this particular pressure device. Since arterial oxygen saturation rose to only 80% with oxygen breathing, a higher F_IO_2 (.35 to .4), resulting in an oxygen saturation of 97-98% would provide substantially greater oxygen transport than a 2 psi chamber. Whether this would result in a greater therapeutic effect is unclear, since the question of the optimum therapeutic F_IO_2 or SaO_2% level is unanswered; a value of 85% SaO_2 may be just as effective as 95%. Although this first study of a comparison of oxygen and descent for treatment of HAPE suggests no difference when limited amounts of pressure and oxygen are used, further testing is necessary with higher pressures, higher F_IO_2 and longer periods of time before firm conclusions can be established.

The finding of a decrease in hemoglobin with pressurization is an intriguing finding of the study. Unfortunately, we had no measurements of hematocrit, red cell indices, or hormones regulating fluid balance. Nor did we have an adequate number of measurements with oxygen breathing. However, the measurements of hemoglobin were reproducible and seemed reliable. A mean decrease of 6% in hemoglobin concentration indicates a 6% increase in plasma volume, which would amount to 300cc in a 70kg male. Presumably, this represents a shift from the interstitial and perhaps other tissues as well, space of the lung into the intravascular space. However, we can only speculate on the mechanism. The fluid shift changes agree with the previous Japanese data which was obtained in controls without symptoms. Curiously, our control subjects did not show any such hemoglobin changes. The reason for this discrepancy is unclear. It could be that the well controls in the Japanese study actually had some degree of fluid retention and redistribution. A more likely reason for the

difference may be the greater pressure used by the Japanese (3.2 psi versus 2.2 psi).

Our study has also shown the potential effectiveness of using a hyperbaric chamber for studying the pathophysiology of high altitude illness. Examining acute improvement in altitude illness allows inferences to be drawn about more gradual physiologic changes which have taken place up to the time of intervention. This may prove to be a fruitful technique, since the subjects can be targeted after they have developed illness in contrast to prospectively studying persons of whom only a few will develop significant illness.

CONCLUSIONS

A simulated descent of 1800m for one hour appeared to have no advantage over breathing 25-28% oxygen for one hour. Increasing the P_IO_2 by pressurization or by raising oxygen concentration appeared equally effective in improving oxygenation and clinical status in subjects with high altitude pulmonary edema. One mechanism of action of descent appears to be mobilization of extravascular fluid back into the intravascular space, as evidenced by an acute reduction in hemoglobin values. Presumably, lung water is being re-absorbed. The portable hyperbaric chamber appears to be an effective, safe and practical method of treating pulmonary edema, avoids the weight and expense of oxygen cylinders, and can be used for long periods of time. Further research is needed to determine the optimal length of treatment with the hyperbaric chamber, the reoccurrence of illness after hyperbaric treatment, and whether oxygen or pressurization is more effective for treatment of high altitude illness over a longer time period. The chamber, since it rapidly reverses HAPE (and presumably AMS) offers an opportunity for correlating physiologic changes with clinical improvement, which will provide insights into pathophysiology.

FUTURE PLANS

Fulfillment of the research goals presented in this proposal is proceeding, as we plan to continue these studies in 1989 and 1990. Currently, we are still working with

NASA on the design of a small, well engineered bag that can reliably handle pressures greater than 2 psi. Additionally, we are designing a small aluminum chamber for these investigations. The chamber will allow one investigator to sit side-by-side with a patient while the chamber is compressed to near sea level pressures. In 1989, we plan to complete studies in more persons with high altitude pulmonary edema and also acute mountain sickness, including measurement of arterial blood gases while pressurized. The one subject that we successfully sampled arterial blood gases from before and during the chamber run encouraged us that the technique can be accomplished, by passing a short arterial line through the chamber wall. We will also study clinical response over a longer time period: up to 4 to 6 hours.

Examining the exact mechanisms of the fluid shift we observed will also be a high priority. Measurements of transthoracic impedance, pulmonary mechanics, and A-a gradient or multiple inert gas techniques will give much more information on the actual change in pulmonary extravascular fluid. On the other hand, measurements of atrial natriuretic peptide, osmolality, vasopressin and other factors involved in fluid shift mechanisms, as well as renal function, will help establish to what extent the fluid shift may be secondary to these factors.

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APPENDIX

1. Data collection forms, and symptom questionnaire.

2. Preliminary study results of Takei, et al.

3. Individual data tables for HAPE and control groups, for both treatments.

4. Specific comments on use of the fabric portable pressure chamber.

APPENDIX 1. Data collection forms, and symptom questionnaire.

DMRP CLINICAL DATA FORM

Investigator:_____
Date_____ Altitude __14K _____Other
Name:_____ I.D.#___
Chief Complaint: ___None

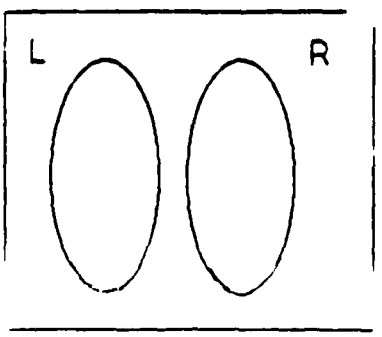
_____
_____
_____
_____

--Age___ Gender M F Nationality_____
--Height(cms)_____ Weight(kg)_____
--Guide Service_____ ___None
--Altitude of Residence_____
--Ascent Profile prior to seeing us: #days 7K--14K_____ #nights @ 14K_____
--When was the last time you were above 3,000 meters?_____
--When did you last spend more than a week's time above 3,000 meters?_____
--Have you ever climbed above 4000 meters? ___Yes ___No
--How many years have you been climbing? _____
--Have you had altitude illness before? **NO** or circle one or more.
AMS HAPE HACE HIGH ALTITUDE HEADACHE
--Do you smoke tobacco? ___Yes ___No
--Medication (include Diamox, ASA, Acetaminophen, sleepers)

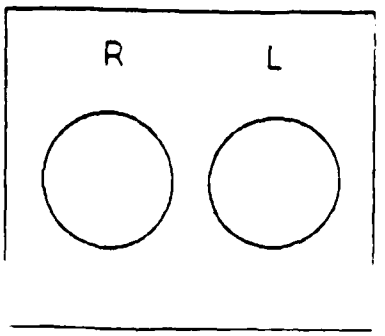
_____
--Allergies (include sulfa)_____
--Past Hx. of altitude illness?_____
--Pertinent PMHx:_____

--Current Predisposing Conditions:
___URI ___bronchospasm ___exertion ___dehydration ___other_____

Vital Signs:
SaO_2%_____ Pulse_____ RR _____ BP_____ Temp_____
General:_____
Skin:_____ Cyanosis: ___Yes ___No
Lungs:_____ **Funduscopic:**_____



Posterior View



Anterior View

DMRP CLINICAL DATA FORM

Rales: ___Yes ___No Location:_____ Cough: ___Yes ___No
Peripheral Edema ___Yes ___No _____
Mental Status:_____
Additional Clinical Data:

_____
_____
_____
_____

Assessment:

____ AMS (mild)
____ AMS (mod)
____ HAPE
____ HACE
____ Cerebral Thrombosis
____ Frostnip location_____
____ Frostbite location_____

____ Hypothermia _____
____ Retinal hemorrhage
____ UV keratitis
____ Dehydration

Plan:

_____
_____
_____
_____
_____
_____
_____
_____

Staff Signature:_____

HYPERBARIA/OXYGEN BREATHING BASELINE MEASUREMENTS

Date:_____ **Name:**_____ **I.D.#**___

___ Informed Consent Completed

___ Sx score completed

___ Clinical data form completed

___ Resting SaO_2

_____ Hemoglobin _____Hematocrit ____FVC ____PF

CEREBRAL BLOOD FLOW MEASUREMENTS

Baseline	**Depth**____	
MCA-V	_____	_____
PI	_____	_____
CO2		
MCA-V	_____	_____
PI	_____	_____
Oxygen		
MCA-V	_____	_____
PI	_____	_____

CHAMBER/OXYGEN BREATHING DATA SHEET

MIN	P_B	F_IO_2	F_ICO_2	SaO_2%	P_AO_2	PaO_2	P_ACO_2	$PaCO_2$	A-a	HR	RR	MV	PI
0													
5													
10													
15													
20													
25													
30													
35													
40													
45													
50													
55													
60													

AMS CLINICAL INTERVIEW

Name:_____ **I.D.#**____

SYMPTOM	REMARKS	SCORE	DATE / TIME						
Headache	transient, relieved with analgesic	1							
	severe, or not relieved with analgesic	2							
Insomnia	difficulty falling asleep, frequent waking	1							
Dizziness		1							
Ataxia	difficulty maintaining balance	1							
	steps off line	2							
	falls to ground or cannot finish test	3							
Severe Lassitude	requires assistance for tasks of daily living	3							
Anorexia or nausea	true anorexia, not distaste for diet	1							
Vomiting		2							
Dyspnea on Exertion	dyspnea forces frequent halts, slow to recover	2							
at Rest	marked dyspnea at rest	3							
Global Functional Assessment	no symptoms	0							
	symptoms, but able to continue	1							
	symptoms, stopping ascent	2							
	Intensive medical treatment and/or evacuation to lower altitude required	3							
			TOTAL						

APPENDIX 2

Japanese Study - Takei, et al (5)

--Ambient barometric pressure 450 torr
--Pressurized to 620 torr over 20 minutes (= 3.3 psi)
--620 torr held for 10 minutes

15 "AMS" subjects

	Pre	Post (30 min)
SaO2	67.7	84.3
HR	97.2	84.8
SBP	119.5	118.2
DBP	78.2	77.8
Sx Score	3.6 (range 1-8)	0.15 (2 subjects with scores of one, others =0) (Hackett score)

30 Healthy Controls (no symptoms)

	Pre	Post	p value
SaO2	83.2	85.8	
Hgb	17.7	16.9	<0.01
RBC	5.69	5.44	<0.01
HCT	c.51	c.53	NS
MCV	88.1	92.4	<0.01
MCH	c.32	c.32	NS
MCHC	35.4	33.9	<0.01
O2 Vol %	20.8	20.3	NS

APPENDIX 3. Individual data tables for HAPE and control groups, for both treatments.

HAPE Subjects Hyperbaric Trial

Baseline

ID	SaO2	HR	RR	$P_{ET}O_2$	$P_{ET}CO_2$	PaO_2	$PaCO_2$	PF	HB	PB	FIO_2
12	47	84	24	58.03	19.34	26	23	540	15.4	450	0.21
14	68	90	18	54.80	20.40	24	23	625	16.8	447	0.21
16	60	89	24	45.54	29.02	29	25	630		450	0.21
19	64	87	28	48.76	24.18	30	28	630	13.8	450	0.21
Mean	**59.8**$^{+}$	**87.5**$^{+}$	**23.5**	**51.8**	**23.3**	**27.3**	**24.8**	**606**	**15.3**	**449**	**0.21**
SEM	**4.6**	**1.3**	**2.1**	**2.8**	**2.2**	**1.4**	**1.2**	**22**	**0.9**	**0.8**	

HAPE Subjects Hyperbaric Trial

After 60 minutes at pressure 110 torr above ambient

ID	SaO2	HR	RR	$P_{ET}O_2$	$P_{ET}CO_2$	PaO_2	$PaCO_2$	PF	HB	PB	FIO_2	$FICO_2$
12	69	70	18	71.68	24.58	35	25		14.6	559	0.20	0.01
14	89	80	16	74.46	24.99	32	26	675	14.9	557	0.20	0.02
16	90	78	18	64.76	38.55	41	29	640		561	0.20	0.02
19	91	76	21	75.63	32.70	47	30	600	13.7	558	0.19	0.02
Mean	**84.8***	**76***	**18.3**	**71.6***	**30.2***	**38.8***	**27.5**	**638**	**14.4**	**559**	**0.197**	**0.02**
SEM	**5.3**	**2.2**	**1.0**	**2.4**	**3.4**	**3.3**	**1.2**	**21.7**	**0.4**	**0.9**	**0.001**	**0.003**

* $p < 0.05$ versus baseline

$^{+}$ $p < 0.05$ versus control group

HAPE Subjects Oxygen Breathing

Baseline

ID	SaO2	HR	RR	$P_{ET}O_2$	$P_{ET}CO_2$	PaO_2	$PaCO_2$	PF	HB	PB	FIO_2
12	47	85	24	58.03	19.34	26	23	540	15.4	450	0.21
14	65	90		48.40	19.60	24	23	625	14.9	447	0.21
16	61	97	24	45.54	29.02	29	25	630		450	0.21
19	67	87	28	46.75	29.42	33	30		13.7	450	0.21
Mean	**60**[+]	**89.8**[+]	**25.3**	**49.7**	**24.3**	**28**	**25.3**	**598**	**14.7**	**449**	**0.21**
SEM	**4.5**	**2.6**	**1.3**	**2.9**	**2.8**	**2.0**	**1.7**	**29**	**0.5**	**0.8**	

HAPE Subjects Oxygen Breathing

After 60 minutes breathing oxygen

ID	SaO2	HR	RR	$P_{ET}O_2$	$P_{ET}CO_2$	PaO_2	$PaCO_2$	PF	HB	PB	FIO_2
12	53	80	20	72.54	17.32	29	26			450	0.26
14	89	76		73.20	24.40	38	27	625	14.2	447	0.28
16	85	82	20	65.29	29.82	46	31	630		450	0.25
19	92	70		70.53	26.19	50	30			450	0.26
Mean	**79.8**[*]	**77**[*]		**70.4**[*]	**24.4**	**40.8**	**28.5**	**628**		**449**	**0.26**
SEM	**9.0**	**2.7**		**1.8**	**2.6**	**4.6**	**1.2**	**2.5**		**0.8**	**0.01**

[*] = $p < 0.05$ versus baseline

[+] = $p < 0.05$ versus control group

Control Subjects Hyperbaric Trial

Baseline

ID	SAO2	HR	PACO2	PAO2	HB
1	84	57	26.2	43.01	
2	90	86	23.7	60.05	17.9
3	84	73	26.7	52.27	14.7
4	87	84	22.8	60.95	17.4
5	88	58	30.8	51.20	16.3
6	85	90	23.1	55.46	16.0
7	88	81	21.6	60.52	15.9
8	84	66	22.8	56.20	17.2
9	84	72	23.5	55.55	16.2
10	88	80		55.61	19.8
Mean	**86.2**	**74.7**	**24.6**	**55.1**	**16.8**
S.E.M.	**0.7**	**3.6**	**1.0**	**1.7**	**0.49**

Control Subjects Hyperbaric Trial

After 60 minutes at pressure 110 torr above ambient

ID	SAO2	HR	PACO2	PAO2	HB
1	96	57	27.6	72.64	
2	96	78	23.5	89.53	16.9
3	95	61	18.7	84.50	16.4
4	93	84	20.5	84.83	14.5
5	95	49	19.4	84.15	15.5
6	95	75	22.4	81.44	16.0
7	95	65	24.7	68.41	15.4
8	96	62	26.2	74.95	16.5
9	93	63	32.3	72.58	15.7
10	94	89		78.49	19.5
Mean	**94.8***	**68.3**	**24.4**	**79.2***	**16.3**
S.E.M.	**0.4**	**4.0**	**1.5**	**2.2**	**0.47**

*** = $p < 0.05$ versus baseline**

Control Subjects Oxygen Breathing (FIO2 = 0.28%)

Baseline

ID	SAO2	HR	PACO2	PAO2	HB
1	86	51	28.2	46.92	
2	86	56	23.7	59.00	
3	84	60	19.2	52.27	14.7
4	88	102	20.8	57.77	17.4
5	89	65	19.8	60.59	16.3
6	89	75	22.9	52.00	
7	90	81	25.7	60.52	16.5
8	95	74	26.7	77.42	17.2
9	88	75	32.9	56.26	
10	89	76		55.61	
Mean	**88.4**	**71.5**	**24.4**	**57.8**	**16.4**
S.E.M.	**0.9**	**4.6**	**1.5**	**2.6**	**0.48**

Control Subjects Oxygen Breathing (FIO2 = 0.28%)

After 60 minutes breathing oxygen

ID	SAO2	HR	PACO2	PAO2	HB
1	93	49	28.7	54.74	
2	97	55	23.8	87.12	
3	96	75	26.4	84.50	19.0
4	94	78	24.3	82.14	17.4
5	98	50	29.8	75.24	16.1
6	95	75	26.4	69.60	
7	97	69	23.5	77.81	16.9
8	97	59	23.5	76.63	16.5
9	95	63	28.8	76.61	
10	94	71		78.18	
Mean	**95.6***	**64.4**	**26.1**	**76.3***	**17.2**
S.E.M.	**0.5**	**3.4**	**0.8**	**2.9**	**0.5**

*** = $p < 0.05$ versus baseline**

APPENDIX 4

The chamber proved to be safe; there were no adverse effects, even during the one episode in which the chamber exploded with a subject inside; he was suddenly decompressed from 4 psi above ambient back to ambient pressure. He did not feel ear pain and he went on a few days later to reach the summit. The problem of CO_2 accumulation in the chamber needs to be addressed by changes in technology and use. The accumulation of 1-2% CO_2 presented no danger, but lowered the F_IO_2 in the bag to 0.20 and sometimes 0.19, effectively "raising" the simulated altitude. Gamow, the designer of this bag, has subsequently collected data showing that CO_2 can be kept lower with minimal amount of manual pumping, with the use of a CO_2 scrubber or with a special bladder into which exhaled gas is collected from the patient, and then vented to the outside air.

The chamber is sufficiently easy to use that field troops could accomplish treatment of altitude illness without extensive or lengthy training. However, some type of monitoring of the patients' condition must be done for safety reasons. The vinyl window allows visual contact with the patient, and hand signals can be used, as in any altitude or diving chamber. The wall is quite thin, so that speech communication between inside and outside is easily accomplished. The chamber was exposed to extreme temperatures, which seemed to have no detrimental effect. Most subjects when pressurized reported a feeling of warmth from the compression of the air and actually considered it a pleasant experience. Interestingly, no one complained of feeling claustrophobic. A disadvantage of the chamber is that it may take some time to reach the patient should a problem develop. Especially in those models that are bound with nylon straps that go across the zipper, it may take more than one minute to depressurize and open the zipper sufficiently to reach the person inside.